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EFFECT OF SUPERPLASTIC DEFORMATION ON THE SURFACE ROUGHNESS OF SHEET

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SUMMARY

Superplastic deformation increased the surface roughness of Al and Ti-alloy sheet. The implications for SPF/DB processing are discussed.

To be presented at the International Conference on Superplasticity and Superplastic Forming, Blaine, Washington, USA, 1 to 4 August 1988.

Introduction

SPF/DB [1] involves in situ diffusion bonding after the sheet has undergone large superplastic strain. Bond quality depends primarily on precise process control which is based upon the forming and bonding parameters [2]. Surface roughness is one of the most important parameters affecting solid state bonds since in practice increased surface roughness requires an increase in the bonding time. Plastic deformation is known to increase the surface roughness of CP titanium sheet [3], but although an increase in surface roughness has been reported during superplastic deformation of Ti-alloy sheet [4,5], no roughness measurements were made. Ra values* have therefore been determined for Ti and Al alloy sheets before and after SPF and are reported in this paper. Their significance for forming and bonding of sheet is discussed.

Experimental Details

The alloys in sheet form had the compositions (wt%) of Ti-6Al-4V, Ti-15V-3Cr-3Al-3Sn, Al-2.4Li-1.2Cu-0.7Mg-0.1Zr (LITAL A) and Al-6Zn-2.3Mg-1.7Cu-0.11Zr (7010). Sheet thicknesses and grain sizes are given in Table 1.

Table 1

Effect of Superplastic Strain on Grain Size and Surface Roughness Ra

Material	Sheet Thickness mm	SPF Strain $\bar{\varepsilon}$	Grain Size µm	Ra µm
LITAL A	1.6	0	5	0.35
		1.33 at 540°C	12	2.69
7010 (Unclad)	3.2	0	8-12	0.35
		1.61 at 500°C	12-24	4.42
Ti-6Al-4V	3.2	0	6	0.29
		1.38 at 925°C	15	1.44
Ti-15V-3Cr-3Al-3Sn	2.0	0	38	0.44
		1.1 at 910°C	60	2.62

The Ti-alloys were tested at 910-925°C at an initial strain rate of $3 \times 10^{-4} s^{-1}$ and the Al-alloys at 500-540°C in the range 3×10^{-5} - $8.3 \times 10^{-4} s^{-1}$. Surface roughness in terms of Ra were determined using a Taylor Hobson Talysurf machine with a truncated diamond pyramid stylus having a 2 µm radius and a length in the direction of movement of 5 µm. Total length sampled was 1.25 mm.

Results

The surface of Ti-6Al-4V sheet in the as received state showed ridges with smooth regions between (Fig 1a). After a strain of 1.38 grain boundary sliding was apparent (Fig 1b) and the grain size increased (Table 1) coincident with an increase in Ra value from 0.29 µm to 1.44 µm. A larger Ra value

* Ra is the arithmetic mean of the departure of the profile from the mean line.

of 2.62 μm was obtained for the coarser grained Ti-15-3-3 alloy (Table 1). This alloy is less superplastic and showed less grain boundary sliding but numerous transgranular shear bands (Fig 2). Surface detail on LITAL A tested in air was obscured by oxidation products, but during SPF the increase in the Ra value was much greater than for Ti-6Al-4V (Table 1). The less superplastic 7010 alloy had a larger grain size and showed a greater increase in the Ra values (Table 1). There was evidence of large grain boundary shear with deep local depressions (Fig 3). Unlike Ti-6Al-4V alloy surface, in the Al-alloys the short wavelength roughness was superimposed on a longer wavelength roughness as shown in Fig 4.

Plots of change in surface roughness (ΔRa) v strain are shown in Figs 5-6. The ΔRa values increased with strain and with grain size. Biaxially strained LITAL A appeared to have a lower rate of roughening than uniaxially strained material. For the fine grained alloys the rate of roughening ($\Delta Ra/\varepsilon$) was 1.8-2.3 μm for LITAL A and 0.46-1.1 μm for Ti-6Al-4V.

Discussion

The results show that the surface roughness increased by a factor 5-8 in Ti and Al-alloys during SPF. This increase is significant compared with the surface finish specified for SPF quality Ti-alloy sheet of Ra = 0.5 μm [1], although much higher values are implied by other workers [5]. The maximum Ra values produced in the present tests lie at the upper limit for ground surfaces and at the lower limit for turned or milled surfaces [2]. It should also be noted that roughness or surface area generated by grain boundary sliding may be underestimated by Ra values since the dimensions of the stylus prevented it recording the very narrow grooves between grains.

An increase in surface roughness can affect:

a) reactions between the sheet surface and the environment
b) diffusion bonding of the sheet
c) mechanical properties of the sheet.

Reactions at the sheet surface may be between liquids or gases. For Ti-alloys the most common contaminant is oxygen, sometimes derived from water vapour, which can dissolve in titanium to produce brittle surface layers with a thickness up to 4-5 grain diameters under normal processing conditions. Such layers can be removed by pickling but the depth of contamination would be greater for rougher surfaces and contamination or metal removal to these depths could be severe for thin sheet eg ∿0.25 mm thick after SPF. Al-Li-Mg alloys are subject to both magnesium and lithium loss by oxidation at the surface [6] and this would be enhanced by the increase in surface area and accentuated by the back pressure of gas required to suppress cavitation. The narrow grain boundary grooves associated with grain boundary sliding may increase the difficulty in cleaning such surfaces with liquids, especially when access is restricted in for example fuel tanks or pressure vessels.

An obvious practical consequence of increased surface roughness would be an increase in time required to diffusion bond such surfaces. Theoretical studies [7] suggest the time increase could be greater for the longer wavelength roughness found in the Al-alloys. Other implications for bonding are thicker oxide contamination at both Ti and Al-alloy interfaces which is known to adversely affect bond strength [2], a greater tendency to trap gas at the interface and greater disruption of coatings placed on sheet surfaces either to act as a diffusion aid or as a barrier layer to prevent diffusion bonding. Any contamination or solute loss prior to bonding leads to a double layer at the bond interface. This interface may then remain planar and the joint may be susceptable to delamination or low impact properties [2]. The shear strength of diffusion bonded joints in 7010 Al-alloy was particularly sensitive

to roughness for values of Ra <0.20 (clad sheet). For greater Ra values the shear strength appeared to be insensitive to roughness but the width of the scatter band for bond strength was increased to ± 15% [8].

The potential effect of surface finish on the mechanical properties of sheet is less clear. Roughness on the scale of 1-3 grain diameter might be considered to be equivalent to short cracks. These could reduce the time for crack nucleation in low stress/long life fatigue or at least increase the scatter in test data. This effect might be avoided by pickling, but where this is not possible and if sharp radii give rise to local thinning [1] the roughness effects could become important under fatigue loading conditions. Note that the beneficial effects conferred by residual stresses in machined or worked surfaces are normally absent in SPF sheet.

Conclusions

The surface roughness of thin sheet increases with increase in superplastic strain and with increase in grain size. The increase is greater in Al-alloys than in Ti-alloys. The increase in roughness could have implications for surface reactions, diffusion bonding and for fatigue properties, especially for very thin sections.

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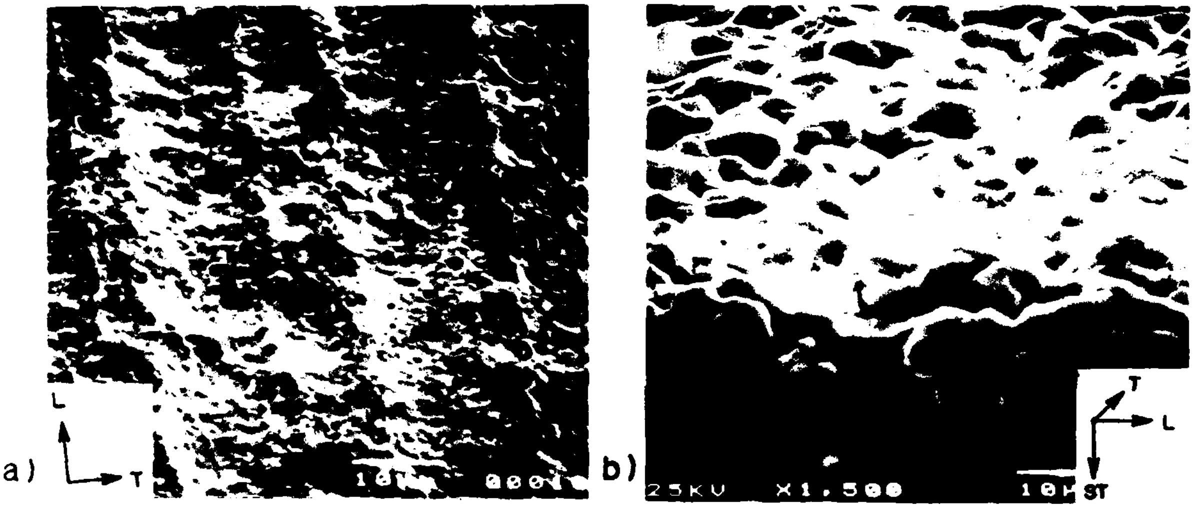

Fig 1 SEM of Ti-6Al-4V surface (a) as received and (b) after superplastic ($\bar{\varepsilon}$ = 1.38)

Fig 2 SEM of Ti-15V-3Cr-3Al-3Sn surface after superplastic strain strain ($\bar{\varepsilon}$ = 1.1)

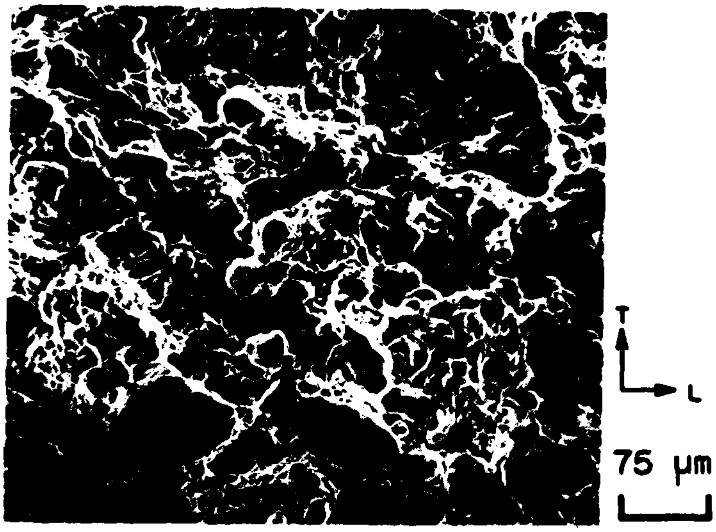

Fig 3 SEM of aluminium alloy (7010) surface after superplastic strain ($\bar{\varepsilon}$ = 1.61)

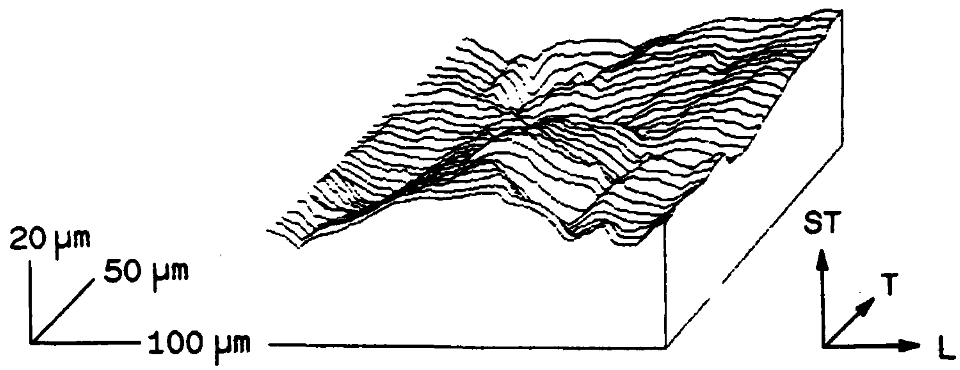

Fig 4 Simulated three-dimensional surface contours of Lital A after superplastic strain ($\bar{\varepsilon}$ = 1.33)

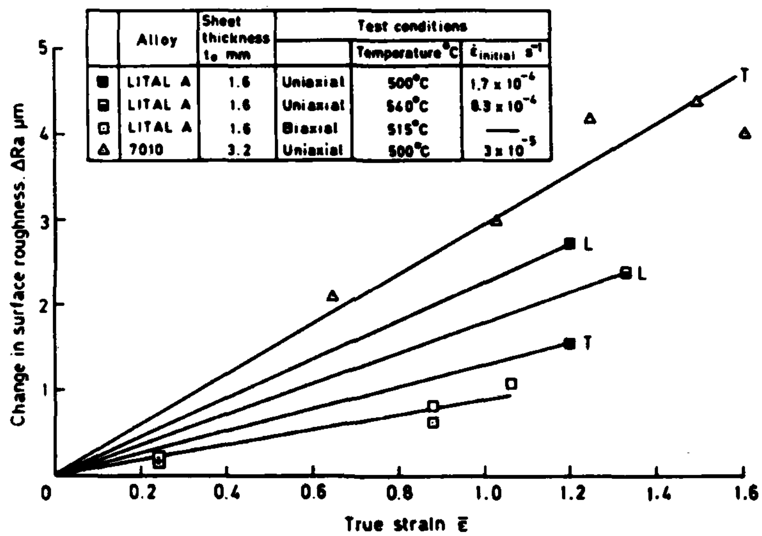

Fig 5 ΔR_a v true strain for aluminium alloys tested under superplastic conditions

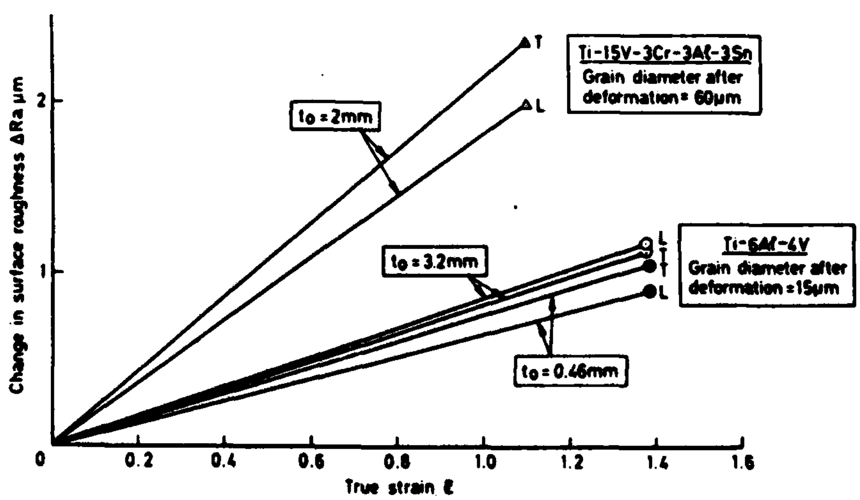

Fig 6 ΔR_a v true strain for titanium alloys tested under superplastic conditions

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17. Abstract

Superplastic deformation increased the surface roughness of Al and Ti-alloy sheet. The implications for SPF/DB processing are discussed.